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ALTERNATE AQUILA RECOVERY SYSTEM DEMONSTRATION RECOVERY SYSTEM --ETC(U)
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ALTERNATE AQUILA RECOVERY SYSTEM DEMONSTRATION

CONTRACT NO. DAAJ02-76-C-0039

RECOVERY SYSTEM FLIGHT TESTS

FINAL REPORT

13160-RSFT

JANUARY 19, 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DSI, Inc., was contracted to develop an alternate recovery system to the Lockheed AQUILA system-arresting hook and cable. A vertical net with disk brake and horizontal air bag was developed and successfully tested using the Sky Eye RPV as a test vehicle at weights up to 150 pounds. This report documents design selection and test data.

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ALTERNATE AQUILA RECOVERY SYSTEM DEMONSTRATION

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FOREWORD

This report describes the work accomplished by Developmental Sciences, Incorporated, Industry, California, in the design, development and testing of an Alternate RPV Recovery System. The work was performed for the United States Army Air Mobility Laboratory, Ft. Eustis, Virginia under contract no. DAAJ02-76-C-0039. The program was performed during the period from July 1976 through November 1976.

The U. S. Army program monitor was Tom Allerdice of the Military Operations Technology Division, Ft. Eustis, Virginia.

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1. INTRODUCTION

1.1 The Army Aquila Mini-RPV has logged several missions and most of the on-board systems have been successfully checked out. One of the remaining question marks in the program is the ability to recover the craft with the existing retrieval scheme.

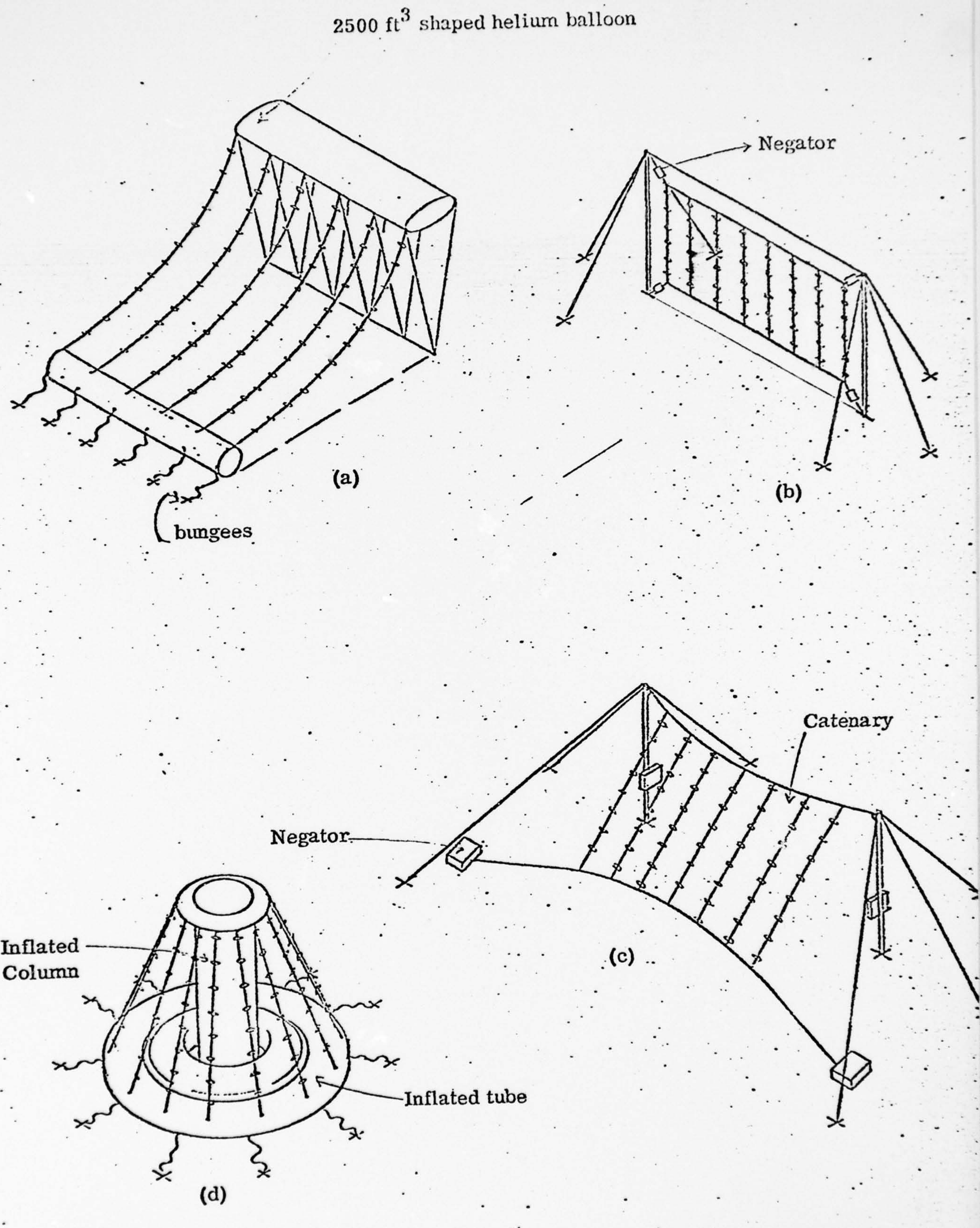
1.2 In January 1976, Developmental Sciences, Inc. proposed a 30 foot high by 50 foot wide curtain of vertical kevlar ropes suspended from a helium-filled shaped balloon. Simple keeper snag mechanisms would be built into each wingtip and small plastic discs spaced along the kevlar ropes would prevent the craft from sliding down the ropes.

In May 1976, Developmental Sciences, Inc. submitted its technical proposal for an Alternate Aquila Recovery System Demonstration per U. S. Army Solicitation DAAJ02-76-Q-0103. in which DSI proposed to build a unique self-erecting retrieval system and conduct a series of recoveries using the SKY EYE I Mini-RPV.

A number of different schemes have been investigated by DSI to erect the recovery window. Figure (1) shows several of the systems investigated. After considerable study, the schemes depicted in Figures (1a) and (1e) were determined to be the most viable from the points of view of safety, practicality, and cost.

Design and analytical efforts were concentrated on variations of the most logical of the systems under consideration.

Figure (2) depicts the general layout of one variation which combines the best features of the two systems analysed. It consists basically of a



RECOVERY SYSTEMS STUDIED

FIGURE (1)

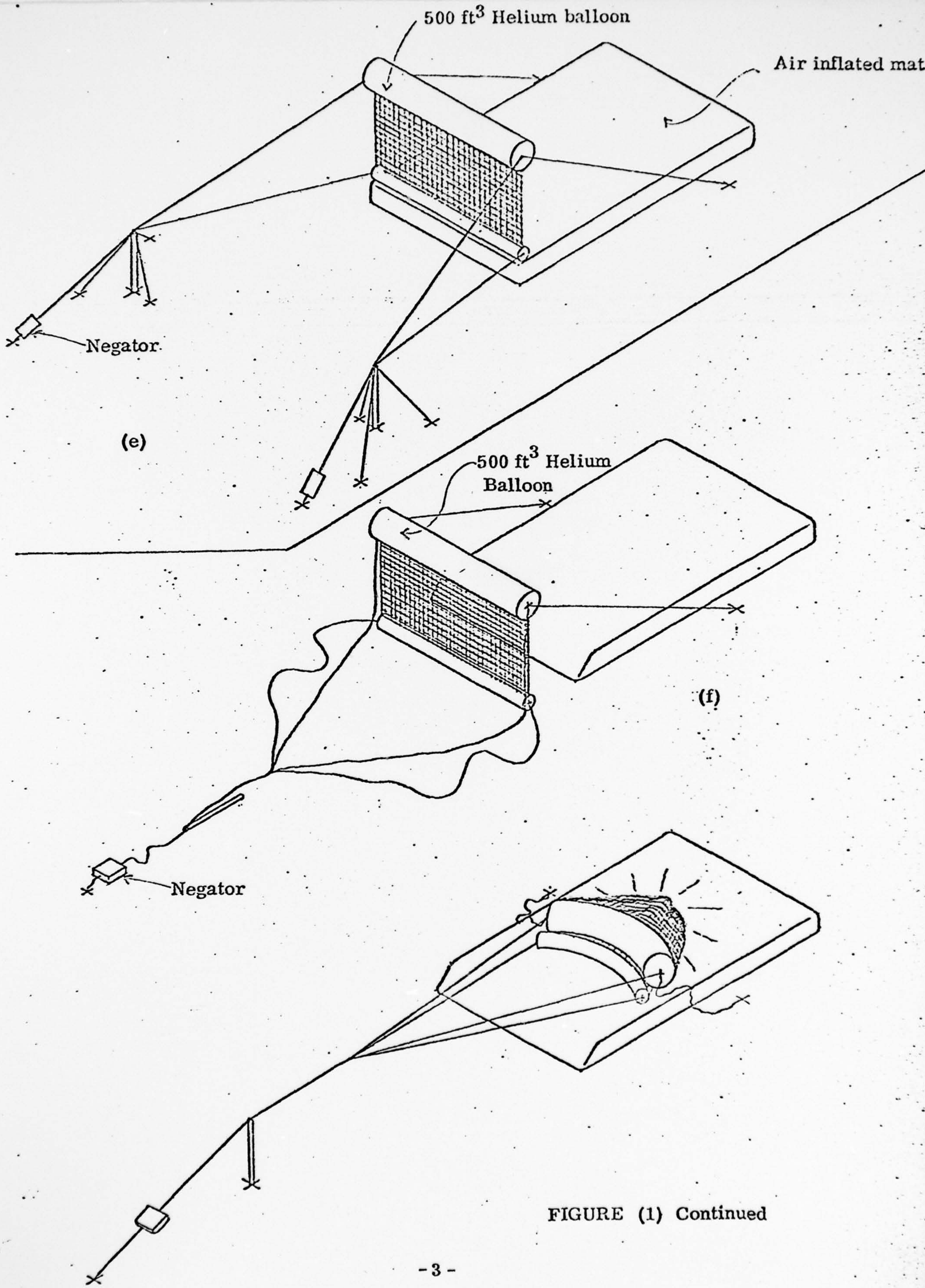


FIGURE (1) Continued

vertical arrestor and a horizontal air mat.

The concept of helium filled balloons was discarded early as being too difficult to handle and too expensive to operate. Since the purpose of the helium balloon was to support the vertical arrestor, it was replaced by a horizontal suspension cable connected to mechanical friction reels mounted on vertical poles. These mechanical friction reels provide the necessary control of the vertical line to prevent whipping and/or wrap around on contact. See appendix for further information.

The RPV had to be equipped with wingtip probes and keepers. These probes were designed to insure positive engagement to the vertical cables. They were strucutrally designed to take a 6 "g" load (on each one) in either the axial or lateral direction. The vertical lines were "free" to slide along the horizontal suspension cable when sufficient force is applied laterally, i.e., running along the leading edge of the wing until the line and keeper set into the wingtip probes.

Final review of the pros and cons of the various concepts simplified both the recovery system ground items as well as the elimination of any special equipment on the RPV.

1.3 The final configuration of the recovery system is shown in Figure (3). It consists of the following components:

1. Air mattress with 4 'pop' open valves and blower for filling and maintaining pressure.
2. Net

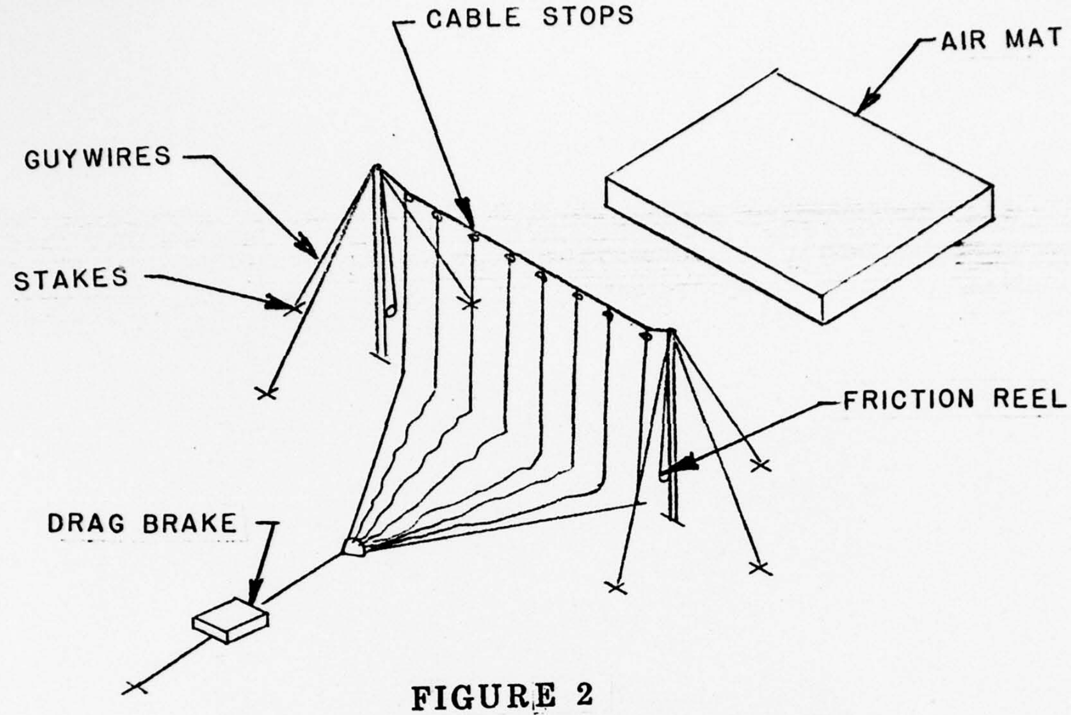


FIGURE 2

PRELIMINARY VERTICAL BARRIER CONCEPT

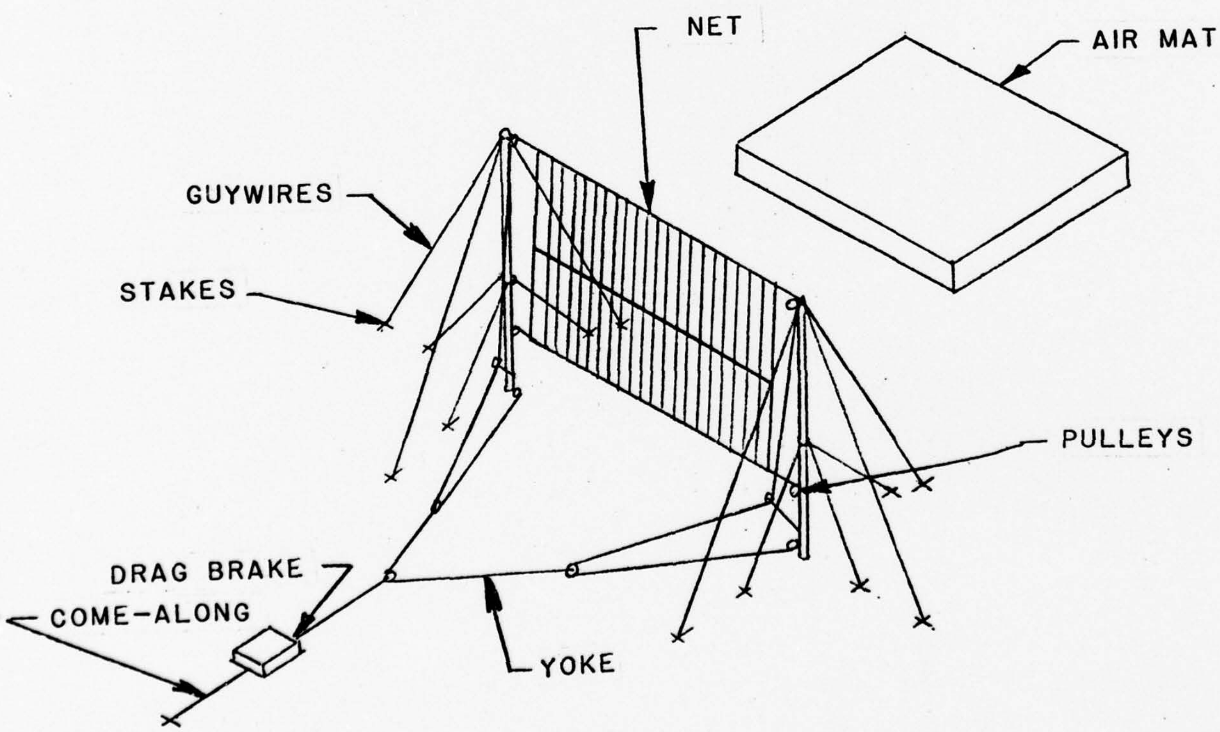


FIGURE 3

FINAL VERTICAL BARRIER

3. Support poles with guy wires, pulleys and ground stakes.

4. Cable yoke with pulleys.

5. Hydraulic drag brake with tensioner (come-along).

In operation, the air mattress is pressurized, the pressure on the hydraulic drag brake is set, the come-along provides pre-load on the net while the yoke equalizes the pre-load.

As the aircraft strikes the net, the lines connecting the upper and lower horizontal lines of the net are reacted at the vertical post pulleys, and transferred to the pulley at the end of the yoke. The yoke then transfers the movement of the yoke by deploying line from the hydraulic drag brake. After the forward velocity of the aircraft is stopped, the aircraft drops onto the air mattress. Contact with the air mattress increases the internal pressure causing the 'pop' valves to open and release the overpressure, thereby reducing the rebound of the aircraft. After the aircraft is removed from atop the air mattress and readied for its next flight, the net is rest by pulling on the hydraulic drag brake line, resetting the drag pressure, if necessary, and readjusting with the come-along.

2. DESIGN ASPECTS

2.1 Design Criteria

The components of the reocvery system were designed for the following criteria:

Aircraft Gross Weight	130 ± 10 lbs
Aircraft Recovery Velocities	50 FPS Min 80 FPS Max
Deceleration Limits, Horizontal	5 'G' Min 6 'G' Max
Deceleration Limits, Vertical	6 'G' Max
Ease of Erecting and Tear Down	

2.2 Cable Geometry and Selection

Figure (4) depicts the cable geometry from the ends of the net to the hydraulic drag brake line. The line from the hydraulic drag brake, started as a jacketed kevlar cable wrapped around a motor cycle wheel with a disc brake attached. In the course of flight tests, this cable was replaced with stainless steel aircraft cable. The kevlar cable used was .127 nominal diameter rated at 2100 lbs. minimum breaking strength. The stainless steel aircraft cable was of similar size and strength. This change was only a precautionary measure after other jacketed kevlar cables produced failures in test. Figure (5) depicts the maximum cable geometry.

The end of the hydraulic drag brake line has a pulley which controls the yoke. The yoke is a 50 foot long cable with pulleys on each end. The yoke cable was .089 diameter jacketed kevlar cable rated at 1200 lbs. minimum breaking strength which was replaced with $^3/_{32}$ diameter stainless steel aircraft cable with the same strength. The purpose of the pulleys is to equalize all restraint lines in the event of off-center contact of the aircraft with the net.

The net cable is a 135 foot long cable with a hook on each end. Figure (6) shows the routing of the cable and the preload and set. Starting at the hook on the upper horizontal web of the net, the cable passes through the pulley

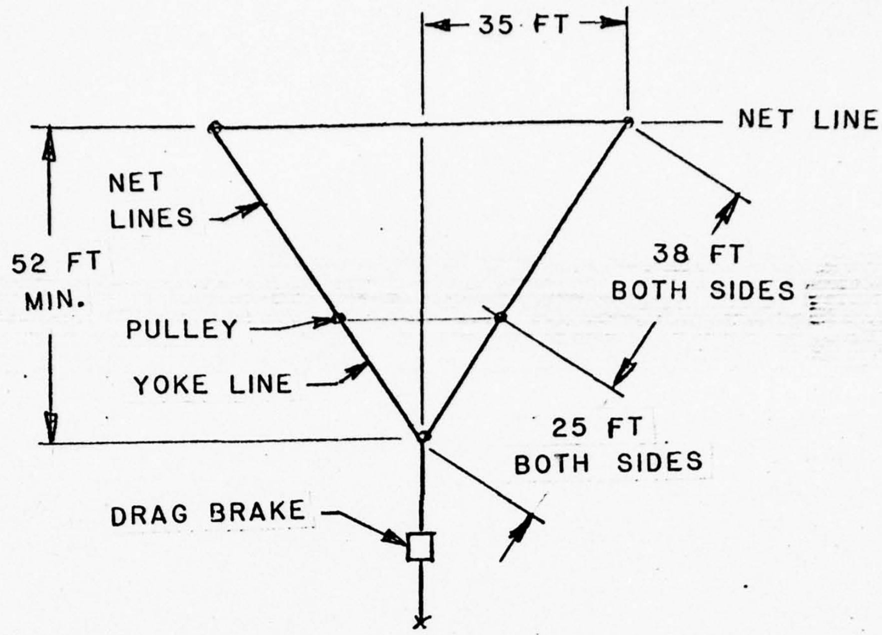


FIGURE 4

VERTICAL BARRIER CABLE GEOMETRY BEFORE RECOVERY

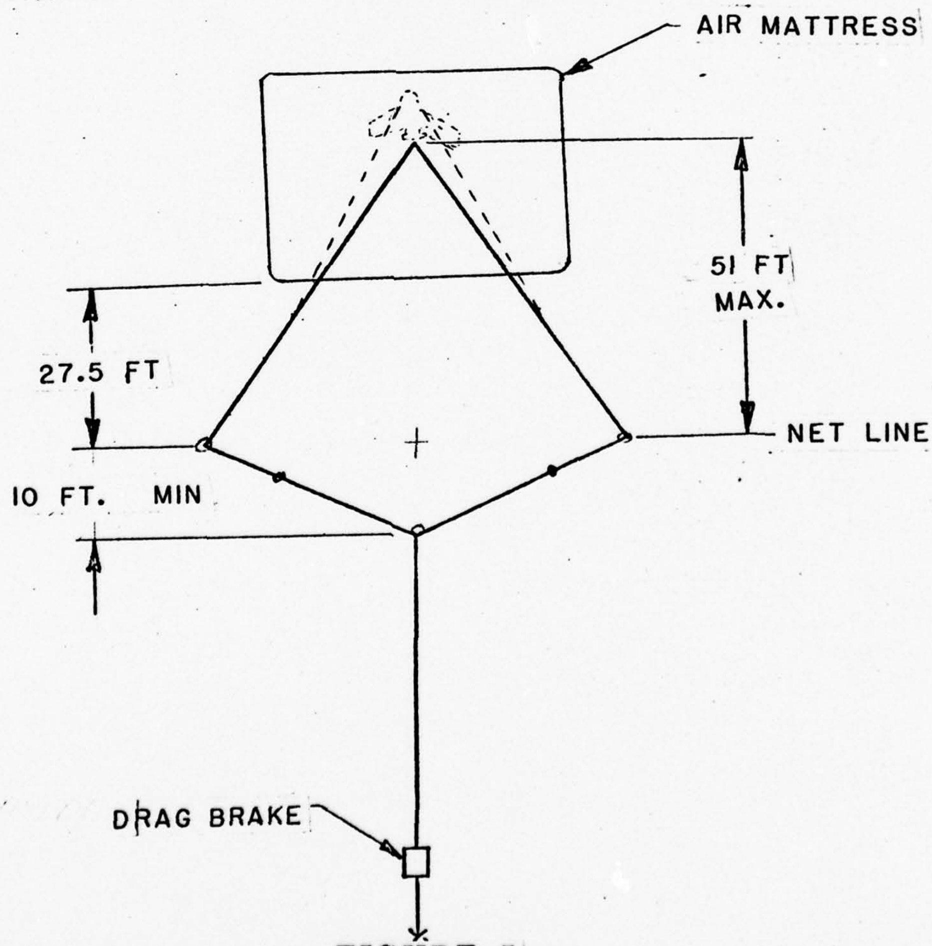


FIGURE 5

VERTICAL BARRIER CABLE GEOMETRY AFTER RECOVERY

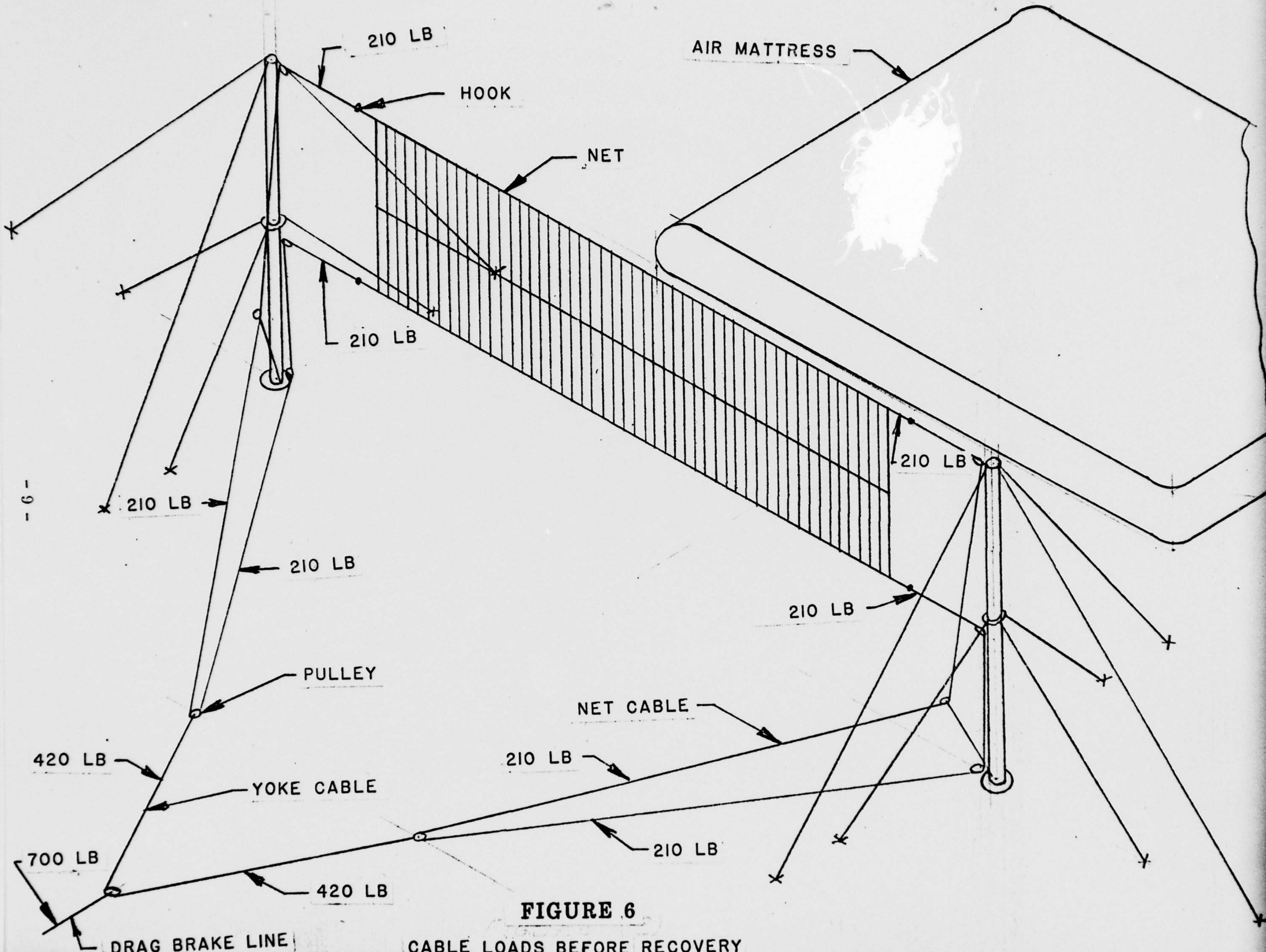


FIGURE 6

CABLE LOADS BEFORE RECOVERY

at the top of the support post, down through a control pulley near the ground line, through the pulley of the yoke cable, through the pulley at the base of the support post, up through the pulley just below the assembly joint of the support post, and hooks onto the lower horizontal web of the net. Figure (7) defines the loads generated in recovery.

The vertical net support posts were set on a flat disc with a ground stake to control base movement and held in place with guy wires at both the top of the support post and at the center assembly joint of the support post. The three legged guy wires were adjustable with turn-buckles in order to remove any slack from the lines.

2.3 The Drag Brake

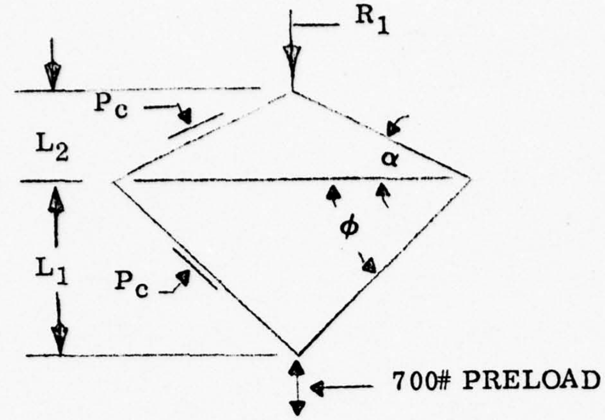
The hydraulic drag brake was originally designed to provide a deployment of cable to satisfy the deceleration limits of 5 'g' $\leq$ a $\leq$ 6 'g' and engagement speed limits of 55 F/S $\leq$ V $\leq$ 80 F/S (V_{stall} to 1.5 V_{stall}). The range of deployment then became

$$S = \frac{V^2}{2\,a}$$

$$S_{max} = \frac{(80)^2}{2\,(5)\,(32)} = 20 \text{ Ft.}$$

$$S_{min} = \frac{(55)^2}{2\,(6)\,(32)} = 7.9 \text{ Ft.}$$

The above calculations were based on a straight line pull from the brake and is based on a constant force reaction.



$$E = \frac{1}{2} M V^2$$

$$V = \sqrt{\frac{2E}{M}} \quad \text{where } M = \frac{150}{32.2}$$

$$V = \sqrt{\frac{E}{2.33}}$$

L_1	L_2	ϕ	α	P_c	R_1	ΔL_2	AVG. R_1	ΔE	TOTAL E	VELOCITY
52.38	0	56° 15'	0	420	0					0
						19.77	215	4250	4250	
46.00	19.77	52° 45'	29° 27'	439	430					42.71
						8.28	505	4181	8431	
40.00	28.05	48° 48'	38° 42'	465	580					60.16
						5.53	632	3494	11925	
35.00	33.58	45° 00	43° 49'	494	682					71.55
						4.75	744	3534	15459	
30.00	38.33	40° 24'	47° 36'	545	804					81.47
						4.07	866	3534	18983	
25.00	42.41	35° 32'	50° 28'	602	928					90.28
						3.45	1024	3532	22515	
20.00	45.86	29° 45'	52° 39'	705	1120					98.32
						2.78	1280	3558	26073	
15.00	48.64	23° 12'	54° 15'	888	1440					105.80
						2.05	1768	3622	29695	
10.00	50.69	15° 56'	55° 22'	1274	2096					112.91

FIGURE (7) CABLE LOADS ANALYSIS

The hydraulic drag brake is composed of a motor cycle wheel with a disc brake and pressure pads on both sides of the wheel. A master brake cylinder is attached to a mounting bracket and an adjustable plunger activates the cylinder. Brake pressure is read on a dial indicater mounted on the pressure line. After each recovery, the pressure must be removed in order to rewind the expended cable. Figure (8) shows the tiedown arrangement of the hydraulic drag brake, from left to right are the reel (motor cycle wheel), the pressure gage above the master cylinder, the come-along tensioner, and the tie down stake.

2.4 The Vertical Barrier

The vertical barrier is a series of vertical ribbons of 1 inch nylon strapping which can withstand 1200 lbs. tension, spaced 12 inches apart. Horizontally at the middle of the net is another 1 inch length of strapping. The upper and lower horizontal straps are 2 inch nylon. The vertical spacing was predicated on ensuring that the wing span would always be trapped between any 2 adjacent webs.

Care must be exercised when folding or unfolding the net. Velcro strips were sewn into the upper horizontal strip so that when folding the net, always hold diagonally oppossed corners and pull taut. Then starting from the upper end about every 6 feet the velco strip can be wrapped around the net until all the net is a single line as shown in Figure (9). With all the velcro strips completed the net can be fed into its carrying bag.

2.5 The Horizontal Mattress

The horizontal mattress was designed to absorb the vertical drop

FIGURE 8

HYDRAULIC DRAG TIE DOWN ARRANGEMENT

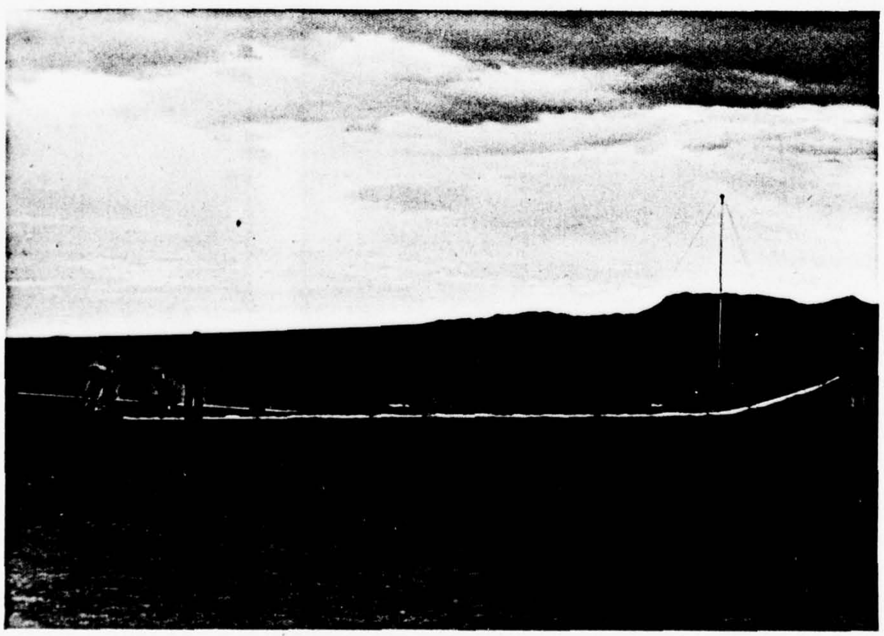


FIGURE 9

UNFOLDING THE VERTICAL BARRIER

of the aircraft after being stopped by the vertical barrier. In establishing the impact velocity, with the aircraft dropping as much as 22 feet, the cushioning thickness is based on the impact velocity where

$$V_Z = \sqrt{2\,a\,S} = (2 \times 32 \times 22)^{1/2} = 37.5 \text{ FT/SEC.}$$

Then the mattress thickness requirement if the vertical deceleration is a constant 6 'g's after impact will be

$$S = \frac{V_Z^{\,2}}{2\,a} = \frac{(37.5)^2}{2 \times 6 \times 32} = 3.66 \text{ FT.}$$

Since there will be some initial force built up, we used a conservative 5 FT. thickness.

The length of the mattress must be at least the range of strokes of the hydraulic drag brake ($S_{max} - S_{min}$) plus one vehicle length plus an allowance for the uncertainties in engagement position and line stretch. A conservative estimate for the uncertainties is less than 10 Ft. Therefore the minimum length of mat should be

$$(S_{max} - S_{min}) + \ell_{veh} + 10$$

$$(20 - 7.9) + 5.5 + 10 = 27.6 \text{ FT}$$

The selected length of the mattress was 35 ft. The selected width of the mattress was 50 ft.

The maximum mat pressure should be 7 times the vehicle weight

distributed over the wing area.

$$P = \frac{7 \times 140}{35} = 28\,\text{PSF} = 5.37\ \text{IN. } H_20$$

The mat outflow must accommodate the initial vertical velocity to avoid pressure overshoot

$$Q = V_Z\, S_{wing} = 37.5 \times 35 = 1312.5\ \text{FT}^3/\text{SEC}$$

The orifice size must allow the maximum outflow at the maximum pressure since the orifice will be fully opened only under these conditions.

$$P = \frac{1}{2}\rho V^2 \qquad \text{where } V = \frac{Q}{A}$$

$$P = \frac{\rho}{2}\,\frac{Q^2}{A^2}$$

$$A = \left(\frac{\rho}{2}\,\frac{Q^2}{\rho}\right)^{1/2}$$

$$A = \left(\frac{.00738}{2}\ \frac{(1312.5)^2}{28}\right)^{1/2} = 15.0\ \text{FT}^2$$

If there are 4 orifices, the diameter of each will be:

$$D = \sqrt{\frac{4}{\pi}\ 3.75} = 2.18\ \text{FT} = 26\ \text{IN DIA.}$$

Actual values used from the original concept are shown in the appendix under Recovery System Calculations. The primary difference between the two sets of calculations is in the vehicle weight increase from 120 lbs. to 140 lbs., and the elimination of the "pull down" effect as depicted in the Maximum Vertical Impact Velocity Calculation.

The material of the air mattress was selected on the basis of strength, weight and ease of fabrication. The strength was verified by the pressure testing and subsequent free fall of an airframe onto the air mattress.

Flight tests determined the need for more protection of the air mattress since sharp objects on the aircraft penetrated the air mattress causing loss of the supporting air. A 22 oz material tarpaulin placed over the air mattress provided the air mattress protection on subsequent recoveries. It should be noted that even when torn, the air mattress did not deflate fast enough to cause any damage to the aircraft.

3. FIELD SELECTION AND SET UP

Select an unobstructed area with a relatively flat size 125 ft. wide and a minimum of 150 ft. long minimum. Divide the length in half and mark a line separating the two halves. Find the middle of that line, mark it and measure off 35 ft. from both directions (see Figure (10)). Mark this position for the location of the vertical barrier posts. Drive a stake in the ground at this location. Assemble the vertical posts with the cabling and pulleys all attached. Raise to the vertical position and stake the guy wires (6 for each post).

Remove the net from its container and straighten it on the ground. Attach the hooks from the cable to the net ring. Caution, make sure the hooks are connected properly. If they become twisted, disconnect the hooks and straighten.

Check the wind direction. Locate the edge of the air mattress on the windward side of the net line. Unfold the air mattress and center between the vertical poles.

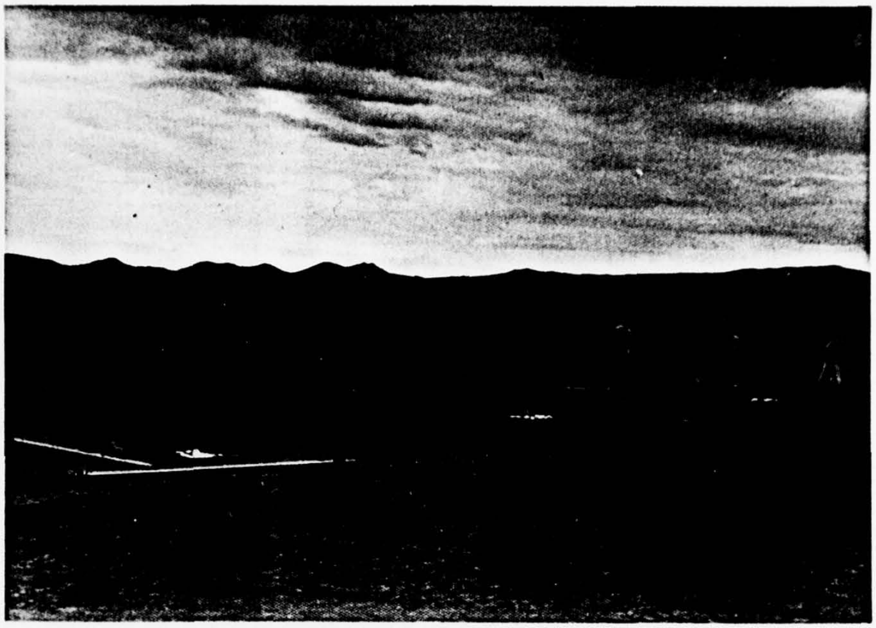


FIGURE 10

LOCATING EQUIPMENT POSITIONS

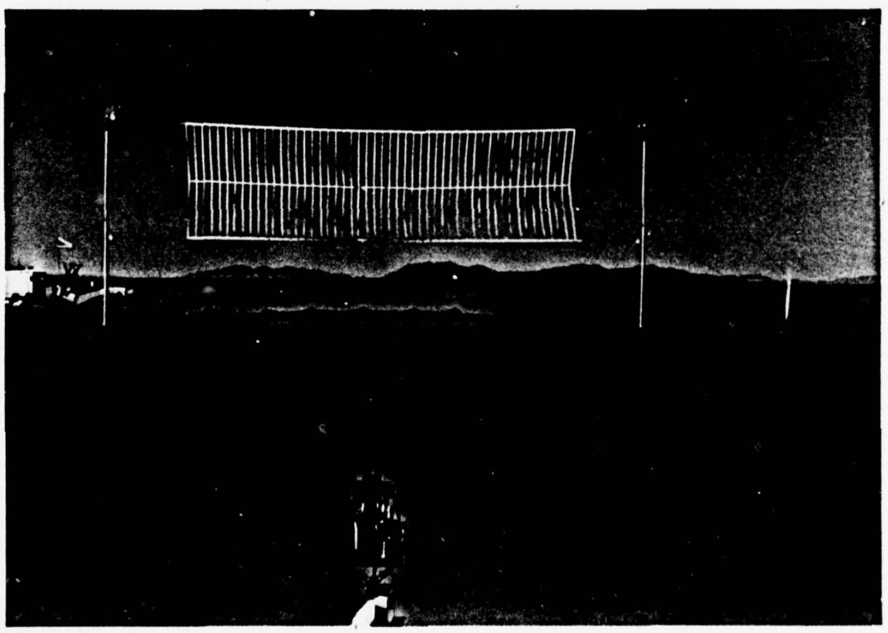


FIGURE 11

COMPLETED FIELD SET UP

The hydraulic drag brake is taken to the opposite end of the field from the air mattress. The yoke is extended until it is tied in with the drag line. A stake in the ground will hold the hydraulic brake system and can be adjusted with the come-along.

The complete set up ready to fly into took 3 men 1 hour 55 minutes (see Figure (11)).

The following is a list of the necessary equipment for the Alternate Recovery System Demonstration.

1. Air Mattress   5' x 35' x 50' inflated

   Weighs 200 lbs., folds into approximate 2' x 3' x 5', fills in about 5 minutes, deflates in about 1 hour, when tarpaulin is left on top.

2. Tarpaulin   22 oz. 30' x 36'

   Weighs about 150 lbs., folds into approximate 2' x 3' x 5'.

3. Vertical Supports   5 1/2" dia. x 13 1/2' long   4 pieces

   Each piece weighs about 30 lbs., can be assembled with guy wires attached in approximately 15 minutes. Straightening of all cables and pulleys must be done before elevating the poles.

4. Net   15' x 50' in elevated position

   Weighs about 7 lbs. Folds into a bag approximately 1' x 2' x 2'.

5. Brake 1 1/4' wide, 1 3/4' high, 2 1/2' long

Weighs about 125 lbs. with master cylinder and pressure gage.

6. Cables, Pulleys, Stakes, etc.

11 pulleys, 12 guy wires, 25 stakes and the come-along weigh about 40 pounds. Stakes are about 1 1/2 ft. long.

7. Valves 1 3/4' dia x approx. 1 1/4 ft. deep 4 req'd.

Weigh about 25 lbs. each. Valve openings in mat must be stretched over valves and taped shut.

8. Air Pump and Inlet Hose

Commercial 2 cycle motor provides sufficient pressure to maintain full air mattress. Weighs about 50 lbs.

	COMPONENT	WEIGHT	PACKING VOLUME
1.	Air Mattress	200 lbs.	30 cu.ft.
2.	Tarpaulin	150 lbs.	30 cu.ft.
3.	Vertical Supports	121 lbs.	30 cu.ft.
4.	Net	7 lbs.	4 cu.ft.
5.	Brake	125 lbs.	10 cu.ft.
6.	Cables, Pulleys, Stakes, etc.	40 lbs.	12 cu.ft.
7.	Valves	100 lbs.	32 cu.ft.
8.	Air Pump and Inlet Hose	50 lbs.	8 cu.ft.
	TOTAL	793 lbs.	156 cu.ft.

FIGURE (12) SUMMARY OF COMPONENT WEIGHTS AND VOLUMES

4. AIRFRAME

The airframe used for the recovery tests was a modification of a previous DSI design which reasonably duplicated the wing planform, the gross weight, and flight characteristics of the Aquila.

The wings were foam filled instead of the honeycomb construction utilized on the Aquila so that field repairs would be easier even with the increased weight of the foam.

Removable landing gear has been a part of the SKY EYE design and permitted the use of the same truck launch techniques whether for training flights or recovery flights.

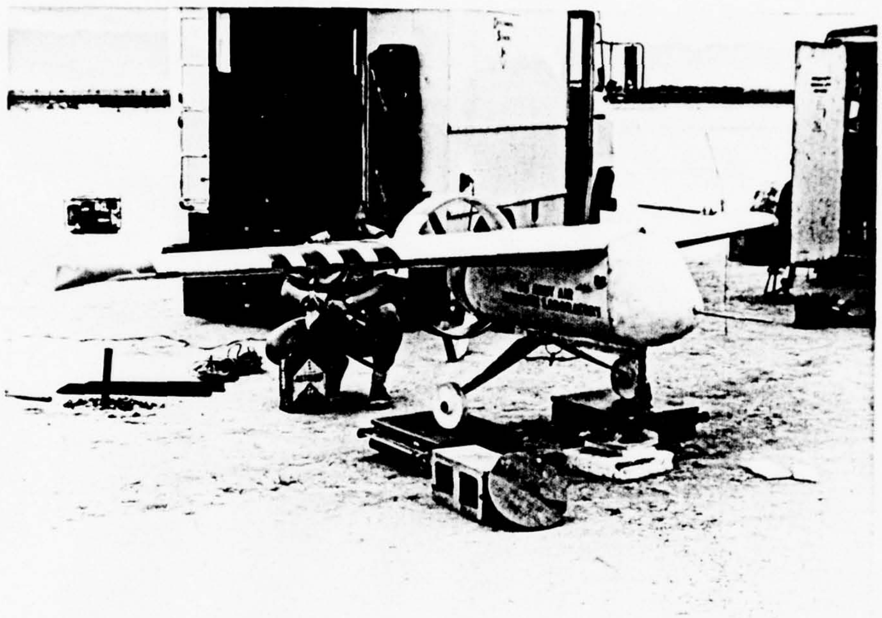
Brackets were made to mount equipment in proper location to minimize dead weight ballasting to maintain proper center of gravity location.

Figure (13) shows the complete airframe with its undercarriage being readied for weight and balance calculations.

5. LAUNCHING SYSTEM

The removable landing gear has the capacity of both take-off and landing when adequate runway is available but for recovery flights, for which the landing gear is removed, a truck launching technique was established.

A work platform and wing support cradle was mounted over the engine compartment and cab of a pickup truck. A bracket on the front bumper supports a removable hoist. Figure (14) shows an aircraft in the process of elevating onto the wing support cradles. Figure (15) shows the aircraft being centered between the wing support cradles.



AIRFRAME WEIGHT AND BALANCE

FIGURE 13

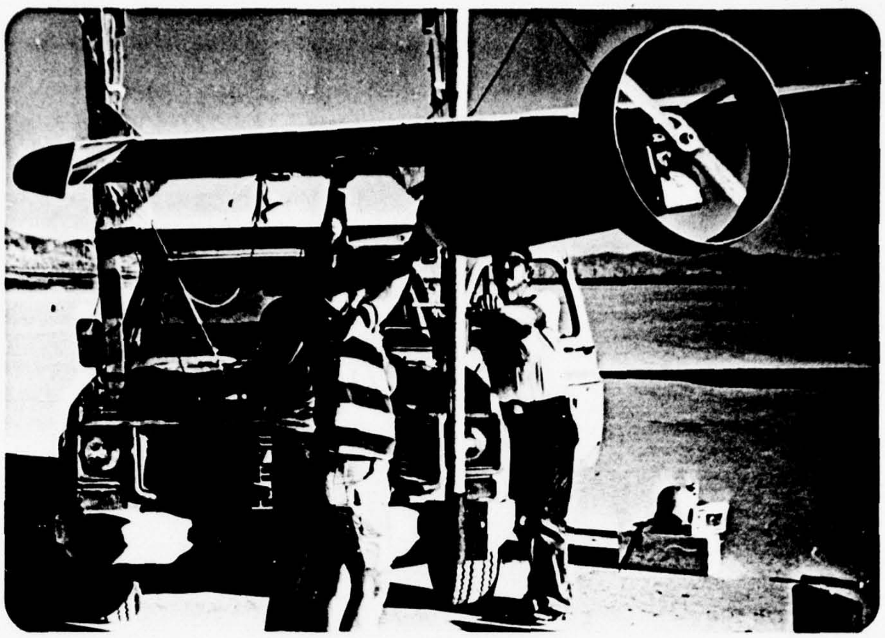


FIGURE 14

HOISTING THE AIRCRAFT ONTO THE LAUNCHER

FIGURE 15

POSITIONING THE AIRCRAFT ON THE LAUNCHER

The hoisting sling is disconnected from the aircraft and the hoist is removed from the truck.

A quick release tie down holds the aircraft onto the wing support cradles until adequate air speed is achieved. An air speed indicator is mounted on the support structure so that the truck driver can determine launch air speed.

Pull on a lanyard releases the tie down and the aircraft is airborne. The photo in Figure (29) was taken an instant after the lanyard was pulled. Note the operators arm still pulling the lanyard.

Calculations of aircraft performance require adequate control of aircraft angle of attack and airspeed to satisfactorily perform the truck launching technique used in this program.

6. ELECTRONICS

The electronics necessary to remotely control the SKY EYE aircraft during both training flights and recovery flights was modified from commerically available radio control electronics to provide higher power output and assure signal strength over a greater distance.

In addition to the aircraft control system, telemetry electronics was incorporated in the system to provide continuous monitoring of the pitch rate gyro. the vertical accelerometer, the horizontal accelerometer, airspeed, and flap positions.

Figure (16) defines the receiving flow path of the telemetry ground control station.

Figure (17) defines the transmitting flow path of the ground control system for controlling the aircraft in flight.

Figure (18) defines the transmitting flow path of the airborne telemetry equipment.

Figure (19) defines the receiving flow path of the airborne control system.

Figure (20) is a list of the required ground control equipment.

Figure (21) is a list of the airborne control equipment.

7. TESTING

7.1 Component Tests

- Air Mattress Tests

A series of tests to determine pressure requirements and valve opening limitations were conducted. The results of these tests are tabulated next page, and determined the use of the lower pressures to reduce rebound.

- Hydraulic Drag Brake Tests

A series of tests were conducted to determine the drag characteristics of the hydraulic drag brake. (See Figure (23)). Both static and dynamics tests were run with comparable results. For the static tests, the brake pressure was established and slippage point read from a dynamometer.

TM GROUND EQUIPMENT

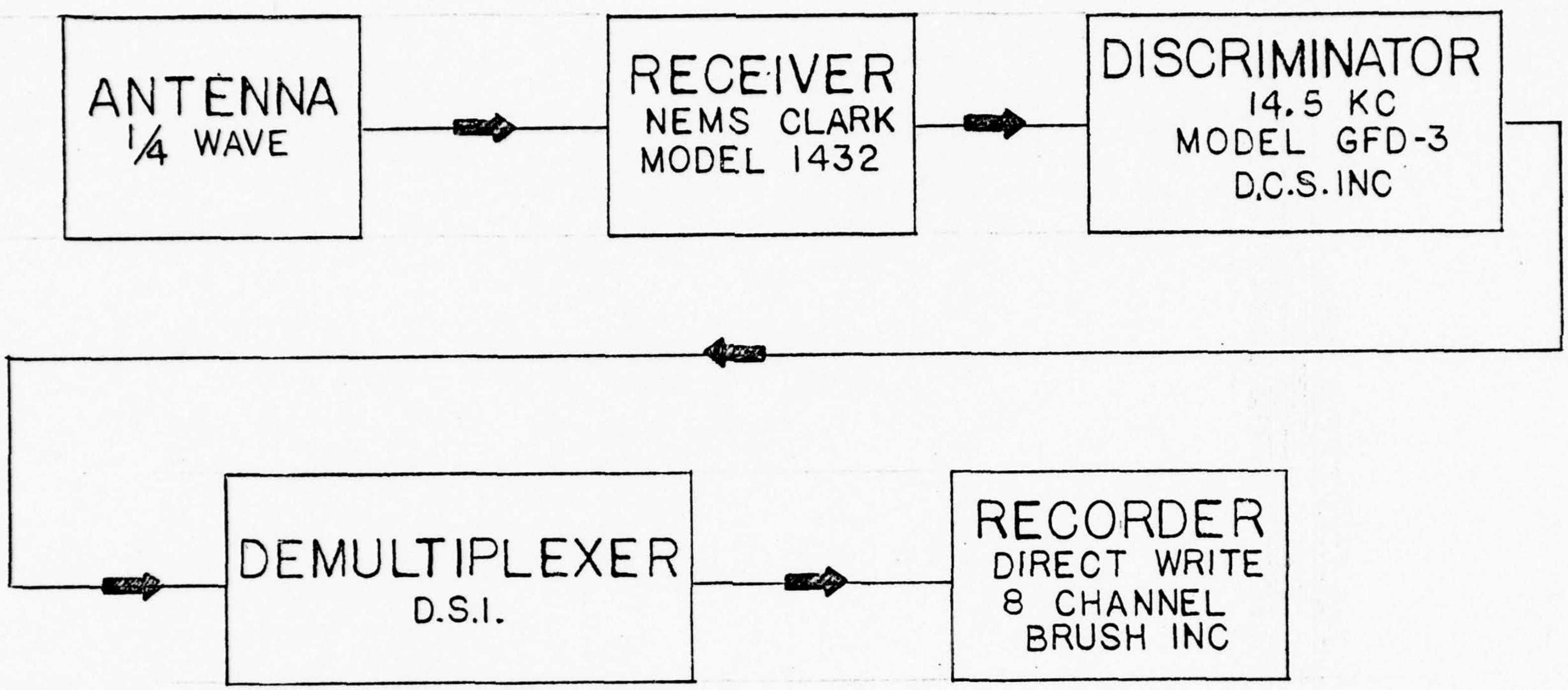


FIGURE 16

CONTROL SYSTEM GROUND EQUIPMENT

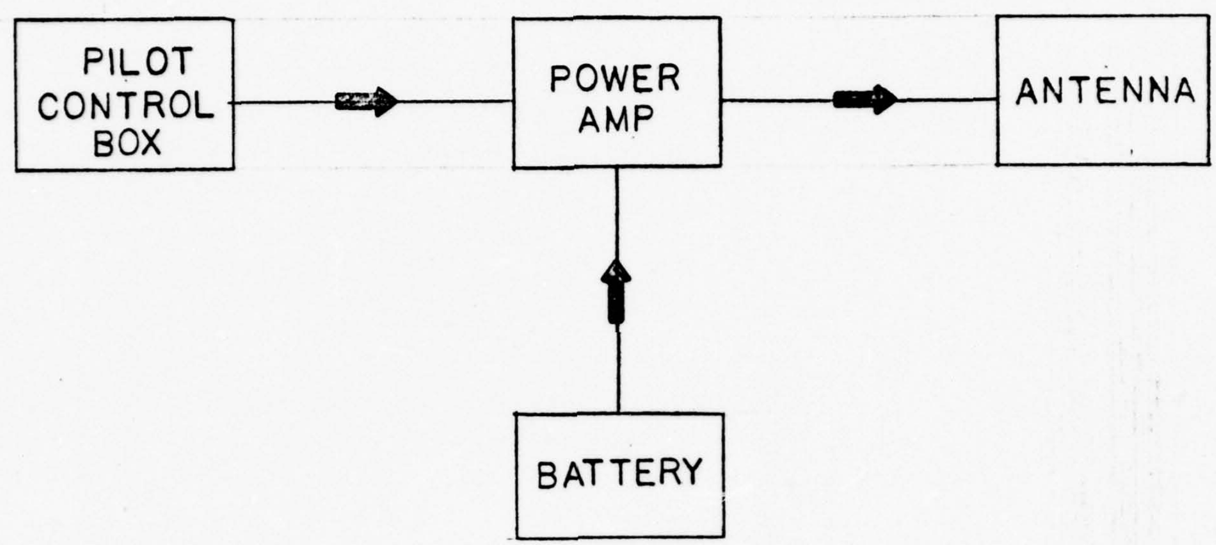


FIGURE 17

TM AIRBORNE EQUIPMENT
PAM-FM-FM

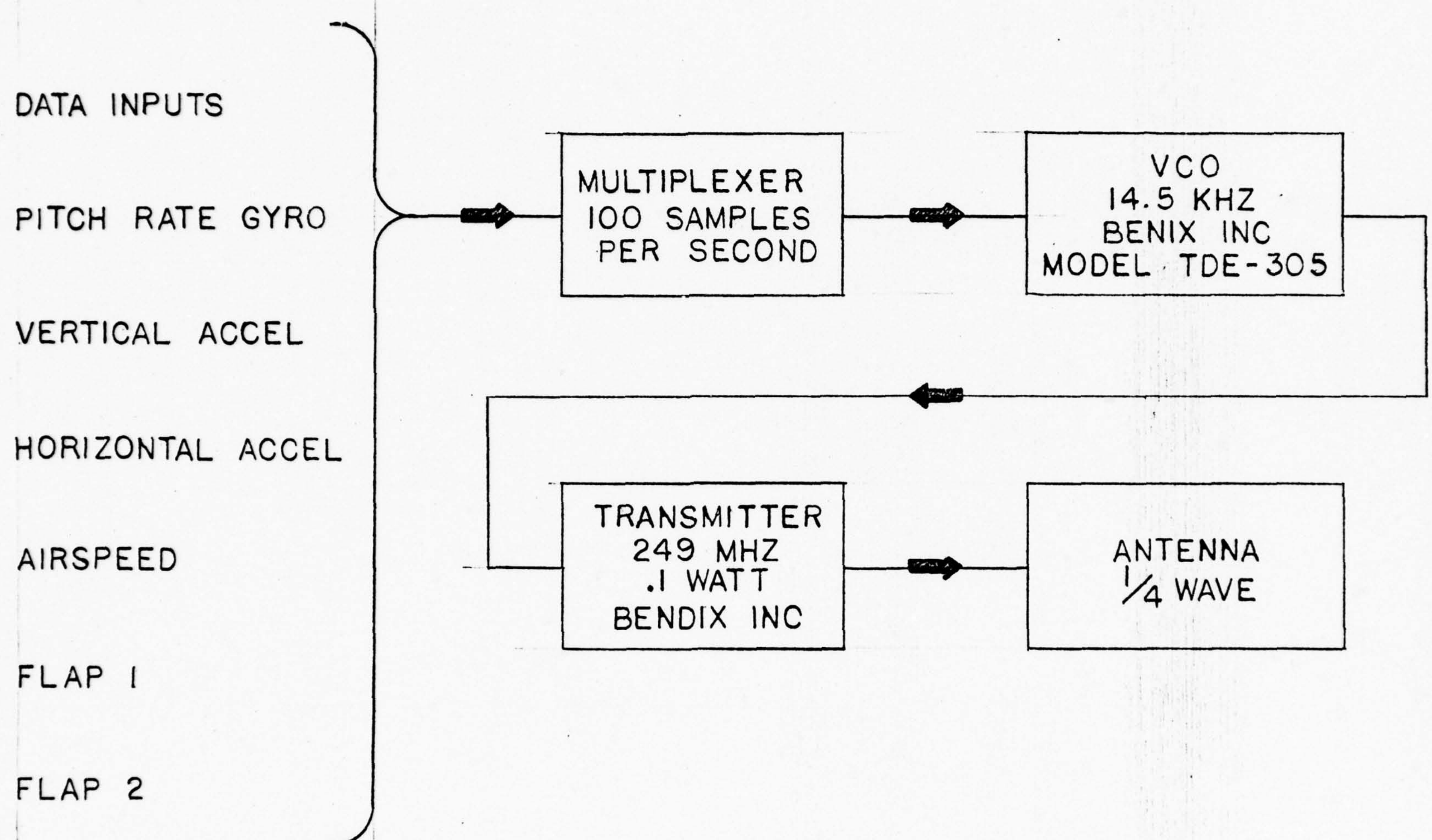


FIGURE 18

CONTROL SYSTEM AIRBORNE EQUIPMENT

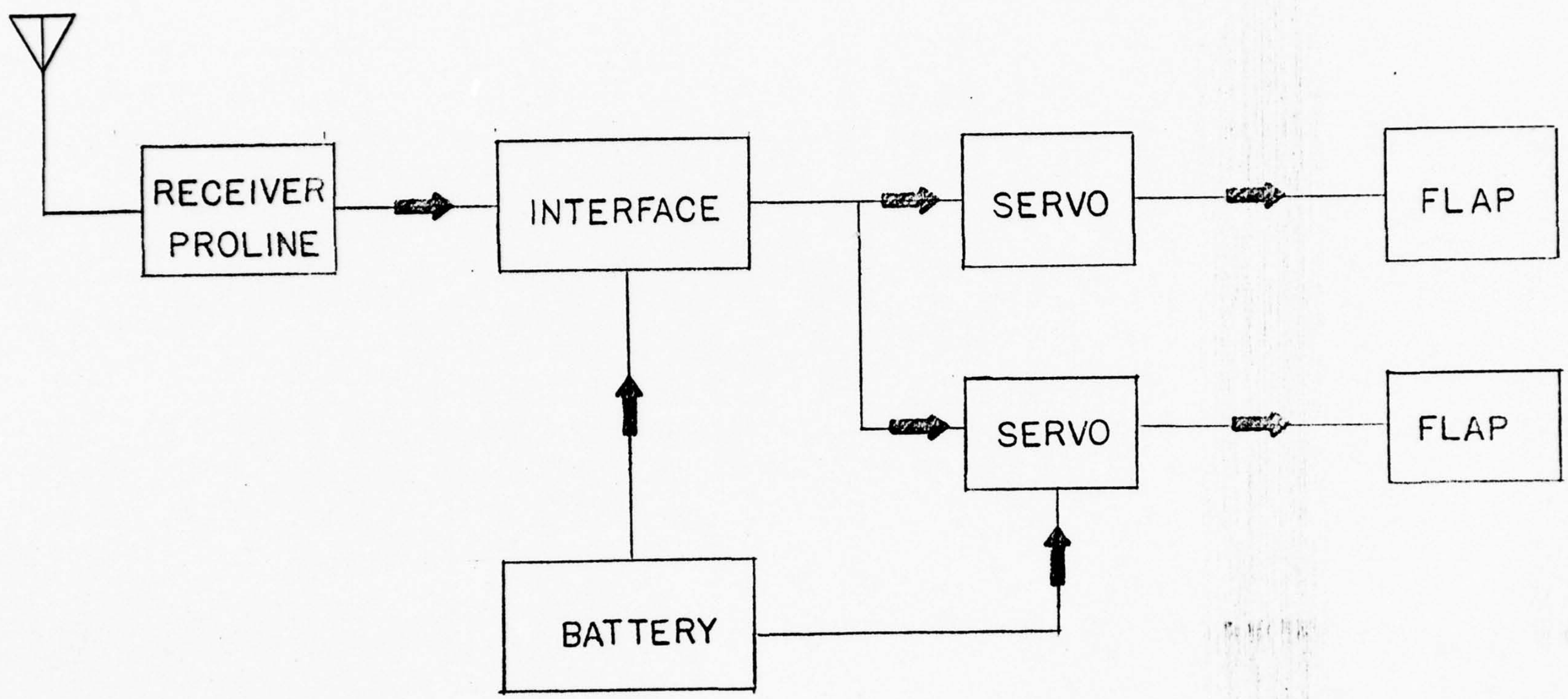


FIGURE 19

GROUND EQUIPMENT

1. PILOT CONTROL BOX.

   PRO LINE INC. TRANSMITTER MODIFIED
   FOR USE WITH POWER AMPLIFIER.

2. POWER AMPLIFIER.

   12 WATTS OUTPUT AT 53.2 MHZ.
   D.S. I. INC. DESIGN.

3. ANTENNA.

   1/4 WAVE GROUND PLANE.

4 BATTERY.

   12 VDC, AUTOMOTIVE TYPE.

FIGURE 20

AIRBORNE EQUIPMENT

1. RECEIVER.	PRO LINE INC. RECEIVER MODIFIED FOR VERTICAL DIPOLE ANTENNA.
2. INTERFACE.	A DIGITAL TO ANALOG CONVERTOR TO DRIVE SERVOS.
3. BATTERY.	24 VDC, 2.0 AMP HOUR, NI-CAD
4. SERVO.	GLOBE 542294 MOTOR WITH ADDITIONAL GEARS AND FOLLOW-UP POTENTIOMETER.

FIGURE 21

Test No.	Drop Height	Initial Pressure	Stabilized Pressure	Accel. Readin	Comments
1	3 ft.	3.4 in H_20	3.1 in H_20	6.1	1 Magnet, 3 Pring Valves
2	5 ft.	3.4 in H_20	3.2 in H_20	6.7	Removed Magnetic Valve
3	6 ft.	3.4 in H_20	3.2 in H_20	6.7	
4	8 ft.	3.0 in H_20	2.9 in H_20	6.0	Reduced Spring Tension
5	8 ft.	2.0 in H_20	2.0 in H_20	8.4	Changed Accel. Gains
6	8 ft.	1.5 in H_20	1.5 in H_20	8.0	Reduced Spring Tension
7	8 ft.	1.0 in H_20	1.0 in H_20	9.0	
8	8 ft.	1.0 in H_20	1.0 in H_20	9.0	Reduced Spring Tension
9	8 ft.	1.0 in H_20	1.0 in H_20	5.7	Reduced Spring Tension
10	8 ft.	1.0 in H_20	1.0 in H_20	8.0	
11	10 ft.	1.0 in H_20	1.0 in H_20	6.5	Reduced Spring Tension

FIGURE (22) AIR MATTRESS TEST RESULTS

DRAG PRESSURE - PSI	SLIPPAGE FORCE - LBS
100	130
120	170
130	185
140	200
150	210
160	230
180	250
200	270
500	600
550	780
600	830

FIGURE (23) HYDRAULIC DRAG BRAKE TEST RESULTS

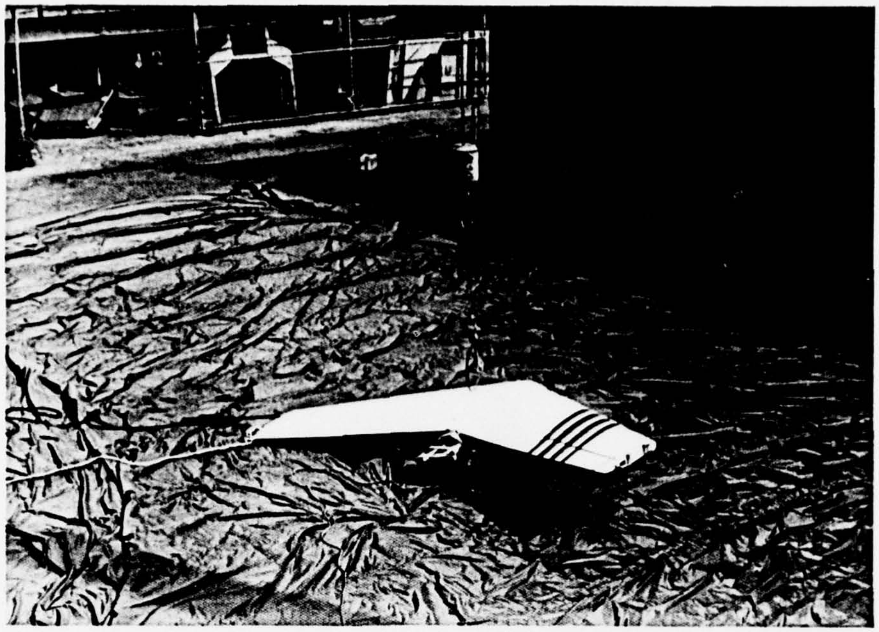


FIGURE 24
AIR MATTRESS TEST PREPARATION

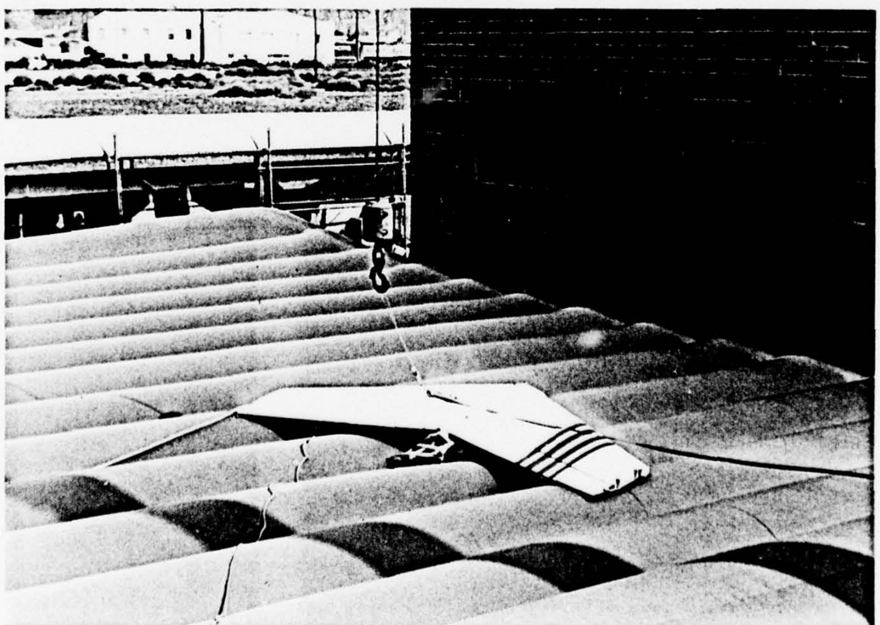


FIGURE 25
AIR MATTRESS AFTER DROP

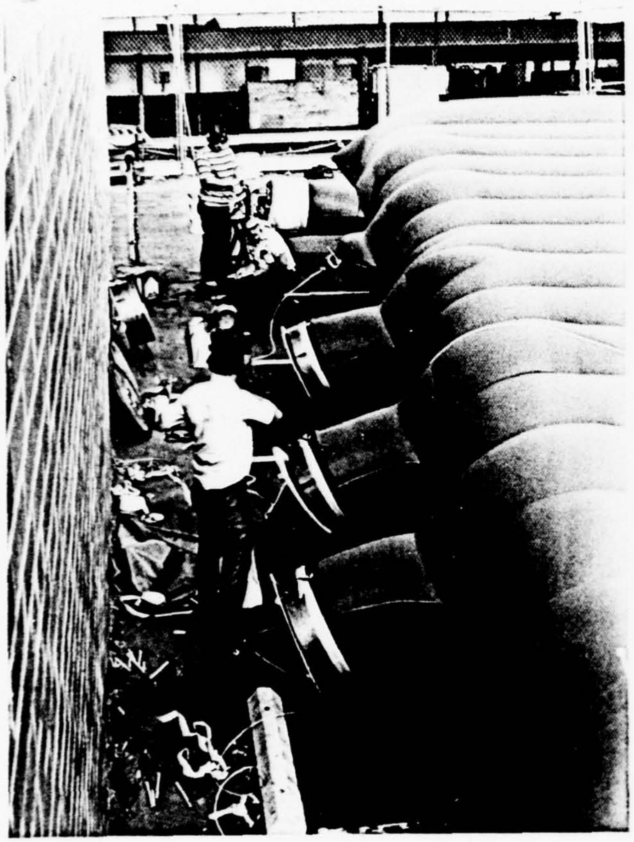


FIGURE 26
AIR MATTRESS TEST
PRESSURE READING

FIGURE 27
AIRCRAFT READY FOR AIR
MATTRESS TEST DROP

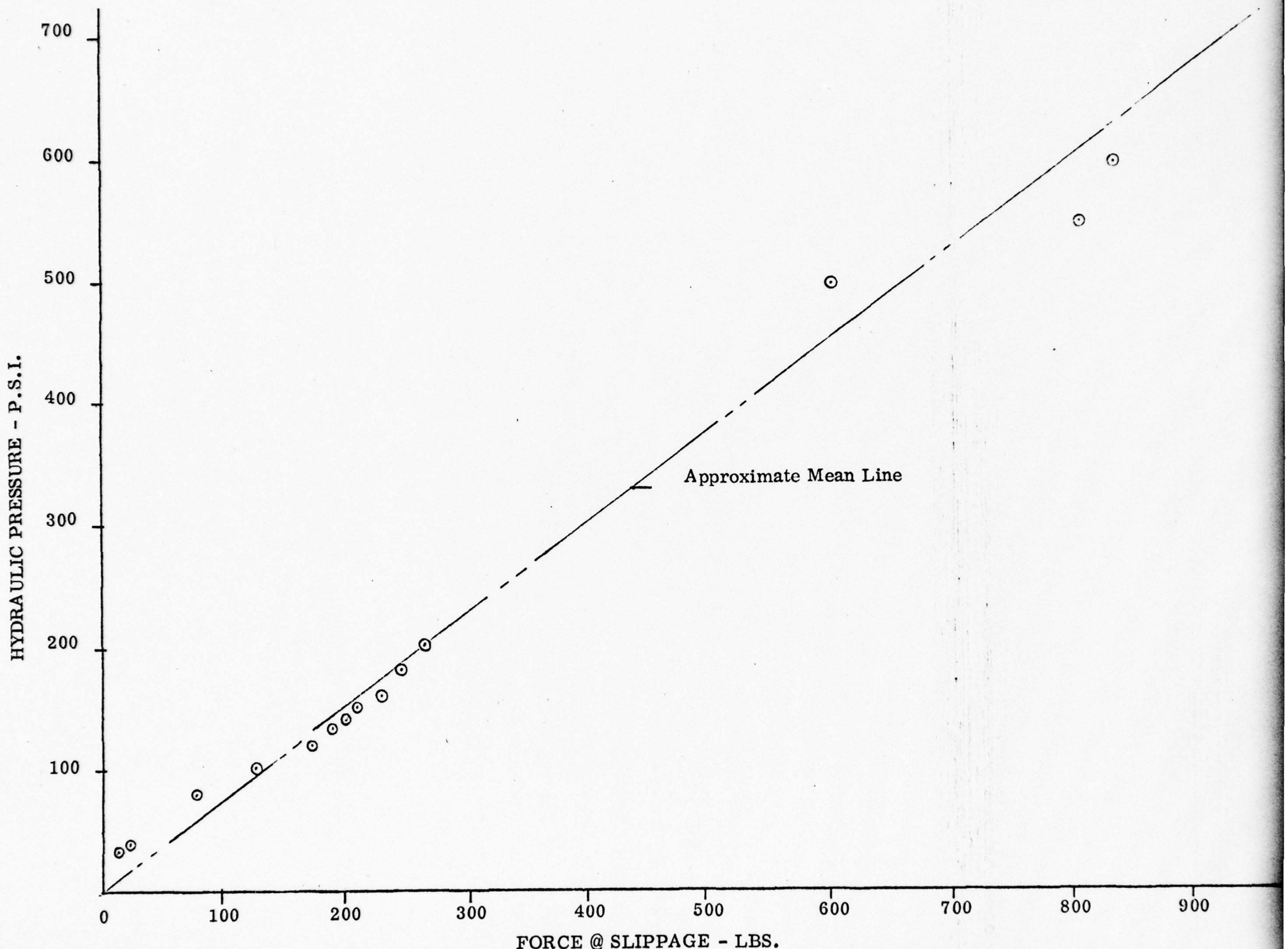


FIGURE (28) HYDRAULIC DRAG BRAKE PRESSURE - FORCE CHART

7.2 Training Flight Tests

Flight No. 1

9-8-76 Bicycle Lake, California

Gross Vehicle Weight	148.00 lbs.
C.G. at 17.5% M.A.C.	F.S. 35.935

Ground run of approximately 1500 feet required for take-off.

Flight Time - Approximately 10 minutes

Flight No. 2

9-15-76 El Mirage, California

Gross Vehicle Weight	145.00 lbs.
C.G. at 19% M.A.C.	F.S. 36.413
Launch Attitude	$+ 5\ 1/2^{o}$
Truck launched at air speed	50 KIAS
Flight Time - Approximately	5 minutes

Flight No. 3

9-16-76 El Mirage, California

Gross Vehicle Weight	145.00 lbs.
C.G. at 19% M.A.C.	F.S. 36.413
Launch Attitude	$+ 5\ 1/2^{o}$
Truck launched at air speed	50 KIAS
Flight Time - Approximately	10 minutes

Flight No. 4

9-16-76 El Mirage, California

Gross Vehicle Weight	145.00 lbs.
C.G. at 19% M.A.C.	F.S. 36.413
Launch Attitude	$+ 5\ 1/2^{o}$
Truck launched at air speed	50 KIAS
Flight Time - Approximately	11 minutes

Flight No. 5

9-16-76 El Mirage, California

Gross Vehicle Weight	145.00 lbs
C.G. at 19% M.A.C.	F.S. 36.413
Launch Attitude	+ 5 1/2°
Truck launched at air speed	50 KIAS
Flight Time - Approximately	11 minutes

Flight No. 6

10-21-76 El Mirage, California

Gross Vehicle Weight	151.7 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2%
Truck launched at air speed	42 KIAS
Flight Time - Approximately	7 minutes

Additional weight due to foam filled wing tips and compensating ballast.

Series of passes through recovery net support poles to train pilot.

Flight No. 7

10-21-76 El Mirage, California

Gross Vehicle Weight	151.7 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2°
Truck launched at air speed	42 KIAS
Flight Time - Approximately	10 minutes

Series of passes through recovery net support poles to train pilot.

Flight No. 8

11-4-76 El Mirage, California

Gross Vehicle Weight	151.7 lbs.
C.G. at 19% M.A.C.	F.S. 36.41

Flight No. 8 (Continued)

Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Flight Time - Approximately	11 minutes

Series of passes through recovery net support poles to train pilot.

Flight No. 9

11-4-76 El Mirage, California

Gross Vehicle Weight	151.7 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Flight Time - Approximately	14 minutes

Series of passes through recovery net support poles to train pilot.

Aircraft hit mogul on lake bed at approximately 15 knots, flipped over on its back. Minor damage to wing, i.e., skin bond delaminated locally. Rebonded in field.

Shroud and wing attach shear pins damaged. Replaced by parts from fuselage 07.

Nose gear minor damage. Straightened in field.

Flight No. 10

11-4-76 El Mirage, California

Gross Vehicle Weight	151.7 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Flight Time - Approximately	7 minutes

Nose gear dug into soft ground at approximately 30 knots, aircraft flipped over on its back. Minor damage to wing, shroud and landing gear. Wing and shroud patched in field. Landing gear removed.

7.3 Recovery Flight Tests

Flight No. 1

11-5-76 El Mirage California

Airframe 06 Wing No. 2

Gross Vehicle Weight	139.2 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2°
Truck launched at air speed	42 KIAS
Recovery velocity at net	60 KIAS
Drag brake set at	550 PSI
Drag brake deployed	22.5 ft.
Vertical accelerometer	6.0 G's
Horizontal accelerometer	6.5 G's

Aircraft came to rest on air mattress 36 feet past net contact line. Right hand pole fell to the ground when support guy wire stake was pulled out of the ground. Guy wire repositioned with two stakes.

Right hand wing tip tore approximate 3 foot long rip in air mattress. Mattress easily patched. No damage to aircraft.

Flight No. 2

11-5-76 El Mirage, California

Airframe 06 Wing No. 2

Gross Vehicle Weight	139.2 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2°
Truck launched at air speed	42 KIAS
Recovery velocity at net	62 KIAS
Drag brake set at	500 PSI
Drag brake deployed	30 ft.
Vertical accelerometer	8.0 G's
Horizontal accelerometer	6.5 G's

Flight No. 2 (continued)

Aircraft came to rest on air mattress 40 feet passed net contact line.

Air speed probe pierced air mattress. Easily patched. Again no damage to aircraft.

Flight No. 3

11-17-76 El Mirage, California

Airframe 06 Wing No. 2 Clear Plastic Nose

Gun camera mounted in nose

Gross Vehicle Weight	142.2 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Recovery velocity at net	54 KIAS
Drag brake set at	475 PSI
Drag brake deployed	0 ft.
Vertical Accelerometer	No Reading
Horizontal Accelerometer	2.2 G's

Retaining kevlar cable broke at pulleys. Aircraft impacted 185 feet passed the net contact line. Plastic nose destroyed. Fuselage bulkheads damaged. Wing hold down block tore out of wing. Minor damage to internal equipment mounting provisions. Internal equipment transferred to airframe 07. Wing No. 3 installed. Aircraft checked out. Telemetry signals erratic during checkout.

A check of the brake setting shows slippage at 700 lbs, dynamometer check, on the 475 PSI pressure setting. One nylon pulley damaged. Kevlar restraining cables all replaced with steel cable. Larger pulleys replaced in yoke pulley. Kevlar guy wires checked. All appeared satisfactory.

Flight No. 4

11-18-76 El Mirage, California

Airframe 07 Wing No. 3 TV camera on-board

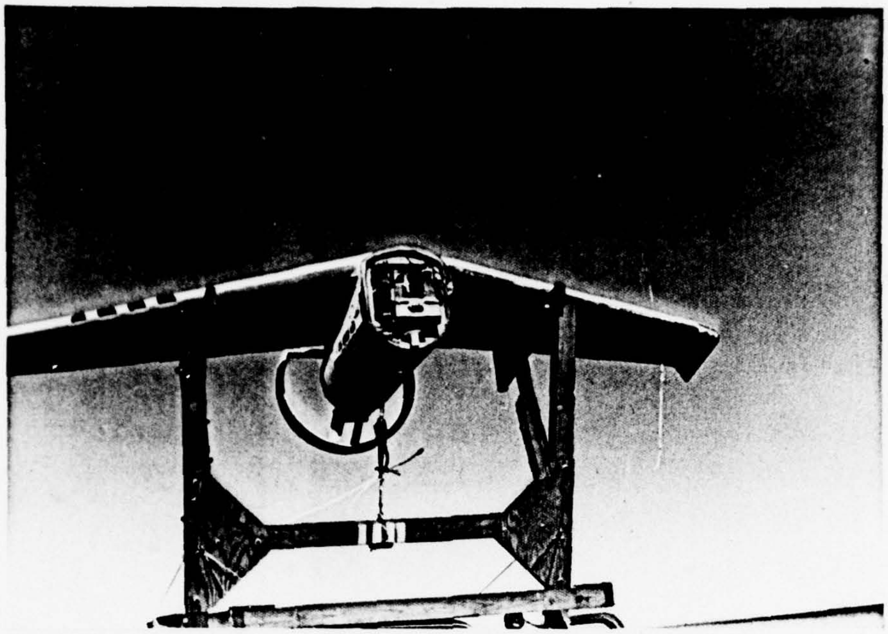


FIGURE 29

RECOVERY FLIGHT 3 WITH MODIFIED NOSE PIECE

FIGURE 30

RECOVERY FLIGHT 3 TEST RESULT

Flight No. 4 (continued)

Gross Vehicle Weight	149.6 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Recovery velocity at net	60 KIAS
Drag brake set at	475 PSI
Drag brake deployed	19 ft.
Vertical Accelerometer	No reading
Horizontal Accelerometer	No reading

Approximately 45 feet passed the net contact line.

Guy wire, kevlar, supporting left hand pole broke. All kevlar guy wires carrying tension replaced by steel cable.

Air speed probe penetrated 22 0Z tarpaulin placed on top of air mattress. One inch long tear in air mattress easily repaired. No damage to aircraft.

Flight No. 5

11-18-76 El Mirage, California

Airframe 07 Wing No. 3 TV camera on-board in place of gun camera

Gross Vehicle Weight	149.6 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Recovery velocity at net	No reading
Drag brake set at	475 PSI
Drag brake deployed	34 ft.
Vertical Accelerometer	No reading
Horizontal Accelerometer	No reading

Aircraft came to rest on air mattress approximately 40 feet passed the net contact line. Aircraft contacted air mattress in a vertical position, setting on its shroud, and fell on its back onto the mattress. Investigation showed the hoisting fitting on the front bulkhead had not been removed for this flight and appeared to have been the cause of the pitch up attitude. There was no damage to the aircraft.

Flight No. 6

11-19-76 El Mirage, California

Airframe 07 Wing No. 3	TV camera removed, Gun camera reinstalled
Gross Vehicle Weight	149.6 lbs.
C.G. at 10% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	No reading
Recovery velocity at net	475 PSI
Drag brake set at	22 ft.
Drag brake deployed	No reading
Vertical Accelerometer	No reading

Aircraft came to rest on air mattress approximately 36 feet passed the net contact line.

Flight No. 7

11-19-76 El Mirage, California

Airframe 07 Wing No. 3	Gun camera on-board
Gross Vehicle Weight	149.6 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	6 1/2^{o}
Truck launched at air speed	42 KIAS
Recovery velocity at net	No reading
Drag brake set at	450 PSI
Drag brake deployed	23 ft.
Vertical Accelerometer	No reading
Horizontal Accelerometer	No reading

Aircraft came to rest on air mattress approximately 36 feet passed the net contact line.

Airframe 07 with wing No. 3 is presently being held by DSI pending Disposition by the U. S. Army. It is in good flight condition and would be an ideal test bed for numerous payload arrangements or engine testing on short notice as demonstrated by the adaptability of on-board television camera, 16 mm camera or any other forward or downward looking element available. Minor modifications are easily adapted to the existing airframe.

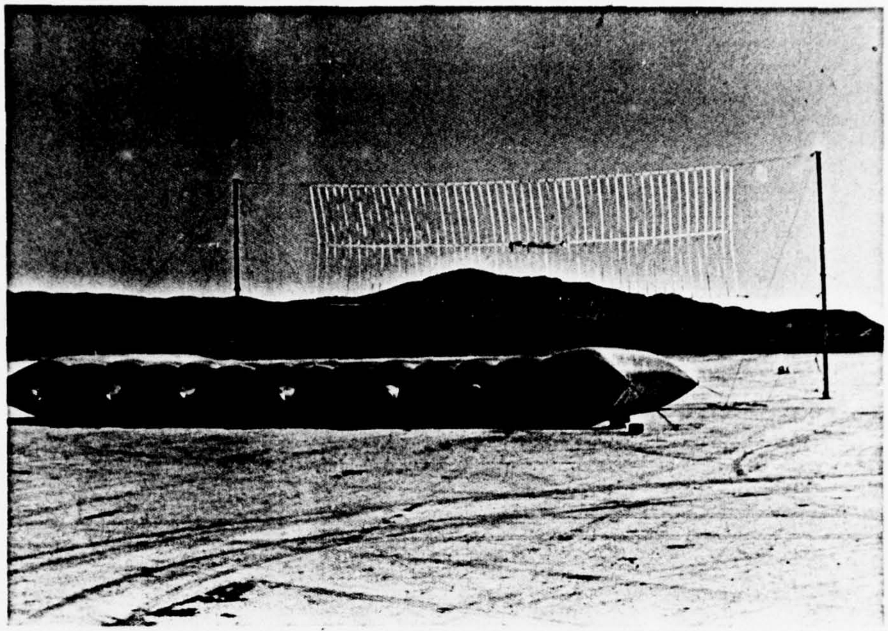


FIGURE 31
VERTICAL BARRIER READY

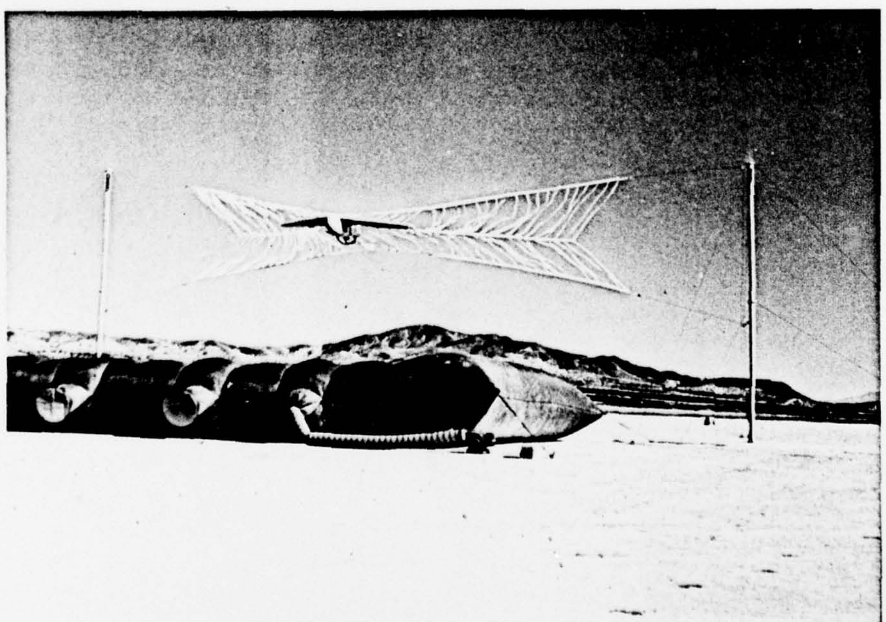


FIGURE 32
VERTICAL BARRIER CONTACT

7.4 Special Flight Tests

In September 1976, the U.S. Army Air Mobility Laboratory directed DSI to bring its flight test vehicles and crew to Ft. Huachuca, Arizona. to evaluate a new recovery system developed by All American Engineering in support of the Aquila program. The objective was to make at least four successful recoveries with this system prior to permitting LMSC to attempt recoveries with Aquila airframes.

During the week of 20 September 1976, DSI sent its test vehicles and flight test crew with its truck launcher and electronics van to Ft. Huachuca, Arizona to train the Aquila radio control pilot and provide the technical assistance for these tests.

Flight No. 8

9-23-76 Ft. Huachuca, Arizona

Airframe 06 Wing No. 2

Gross Vehicle Weight	134 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	5 1/2^{o}
Truck launched at air speed	50 KIAS
Recovery velocity at net	48 KIAS
Vertical Accelerometer	6.5 G's
Horizontal Accelerometer	3.5 G's

Port wing tip slightly damaged by vertical ribbon.

Flight No. 9

9-23-76 Ft. Huachuca, Arizona

Airframe 06 Wing No. 2

Gross Vehicle Weight	134 lbs.

C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	5 1/2^{o}
Truck launched at air speed	50 KIAS
Recovery velocity at net	48 KIAS
Vertical Accelerometer	4.0 G's
Horizontal Accelerometer	3.0 G's

Airspeed pitot damaged, more cuts in port wing tip.

<u>Flight No. 10</u>

9-27-76 Ft. Huachuca, Arizona

Airframe 06 Wing No. 2

Gross Vehicle Weight	134 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	5 1/2^{o}
Truck launched at air speed	50 KIAS
Recovery velocity at net	50 KIAS
Vertical Accelerometer	6.0 + G's
Horizontal Accelerometer	4.0 G's

Port wing tip torn off during recovery. Replaced with tip from Wing No. 1.

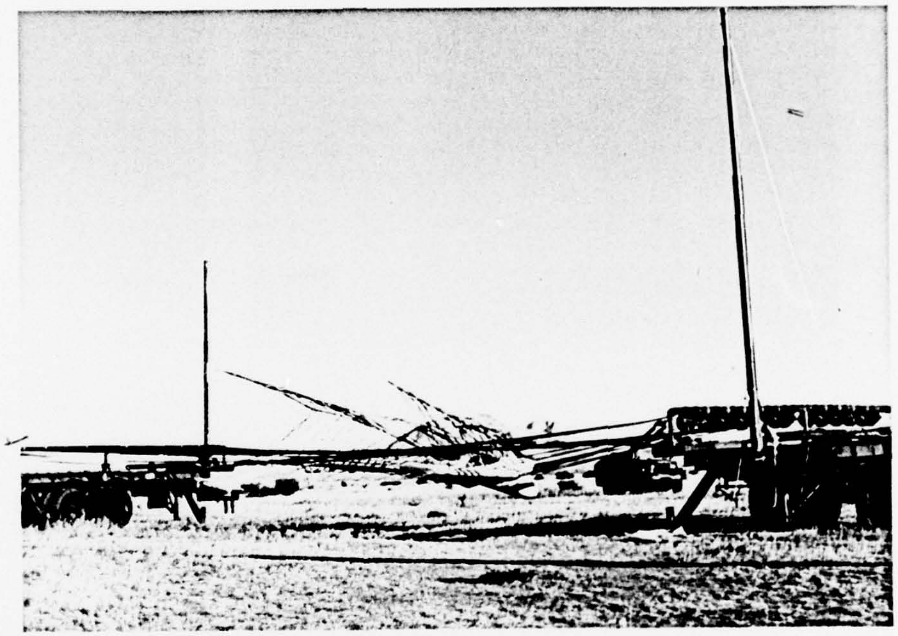
<u>Flight No. 11</u>

9-27-76 Ft. Huachuca, Arizona

Airframe 06 Wing No. 2

Gross Vehicle Weight	134 lbs.
C.G. at 19% M.A.C.	F.S. 36.41
Launch Attitude	5 1/2^{o}
Truck launched at air speed	50 KIAS
Recovery velocity at net	63 KIAS
Vertical Accelerometer	6.0 G's
Horizontal Accelerometer	4.6 G's

Figure (27) shows the results of one of these flights.



RECOVERY AT FT. HUACHUCA, ARIZONA

FIGURE 33

FIGURE 34
STARTING LAUNCH RUN
FT. HUACHUCA, ARIZONA

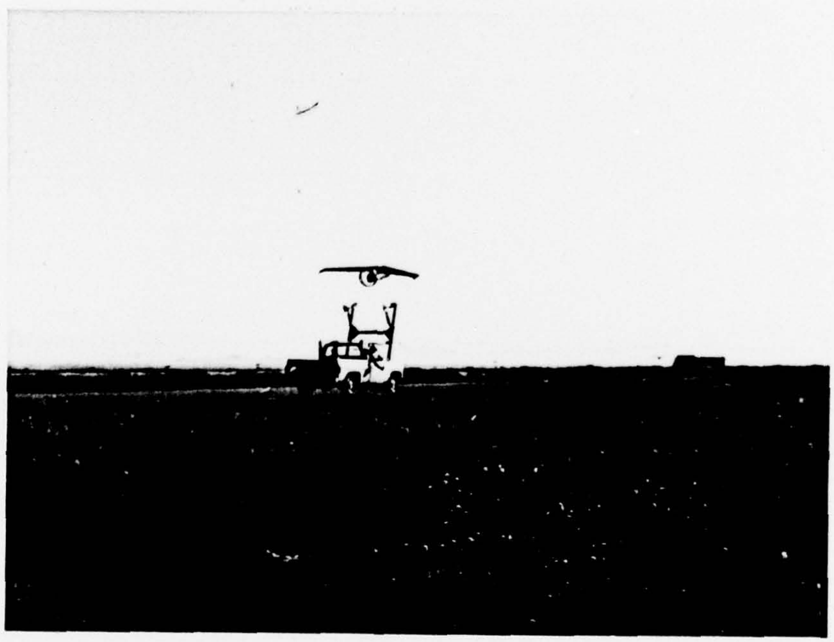


FIGURE 35
LAUNCH
FT. HUACHUCA, ARIZONA

Recovery No.	V. Accel.	H. Accel.	Recovery V - KIAS	Brake Press. P.S.I.	Deploy FT.	Aircraft Wt. LBS.	Comments
1. El Mirage, CA.	6.0	6.5	60	550	22.5	139.2	
2. El Mirage, CA.	8.0	6.5	62	500	30.0	139.2	
3. El Mirage, CA.	--	2.2	54	475	0	142.2	Net Cables Broke Aircraft Damaged
4. El Mirage, CA.	--	--	60	475	19.0	149.6	
5. El Mirage, CA.	--	--	--	475	34.0	149.6	
6. El Mirage, CA.	--	--	--	475	22.0	149.6	
7. El Mirage, CA.	--	--	--	450	23.0	149.6	
8. Ft. Huachuca, AZ.	6.5	3.5	48	--	--	134.0	
9. Ft. Huachuca, AZ.	4.0	3.0	48	--	--	134.0	
10. Ft. Huachuca, AZ.	6.0 +	4.0	50	--	--	134.0	
11. Ft. Huachuca, AZ.	6.0	4.6	63	--	--	134.0	

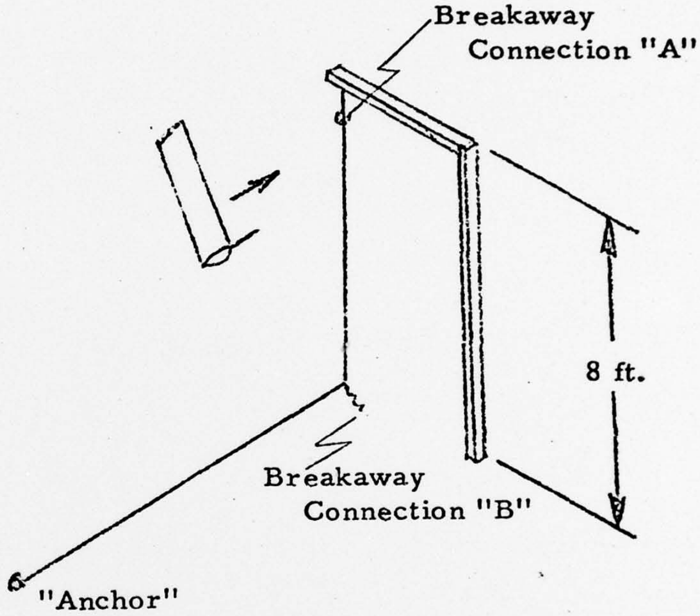
FIGURE (36) RECOVERY FLIGHT SUMMARIES

APPENDIX A

A.1 PRELIMINARY TESTS

DSI has conducted a series of simple snag tests to evaluate the ability of the wing tip probe to positively engage and retain the cable.

A vertical cable was suspended from a pole as shown in the sketch below. Connection "A" and "B" could be made to break away at different loads, could be spring loaded, etc.



A simple wing tip probe and keeper was fabricated and attached to the end of an old SKY EYE elevon. This device was mounted on the side of a truck at a sweep angle corresponding to that of the AQUILA/SKY EYE leading edge. Approach speed was 40 mph.

It was found that engagement was impossible if the connection at "A" was a simple breakaway, since severe cable whip would result. However, if a spring was mounted between the breakaway and the cable positive engagement could be achieved consistantly. It is the evident that the top of the vertical

cable must be restrained from whipping until the stop is reached.

From these experiments, it was decided to restrain these cables through the mechanical drag reels tensioning the horizontal suspension cable.

A.2 RECOVERY SYSTEM CALCULATIONS

A.2.1 Length of Horizontal Stroke

Deceleration limits: $5g \leq a \leq 6g$

Engagement speed limits: $55 \text{ f/s} \leq V \leq 80 \text{ f/s}$ $\left(V_{stall} \text{ to } 1.5\ V_{stall}\right)$

The range of deceleration strokes is:

$$S = 1/2 \frac{V^2}{a}$$

$$S_{max} = 1/2 \frac{(80)^2}{5(32)} = 20 \text{ ft.}$$

$$S_{min} = 1/2 \frac{(55)^2}{6(32)} = 7.9 \text{ ft.}$$

A.2.2 Length of Mat

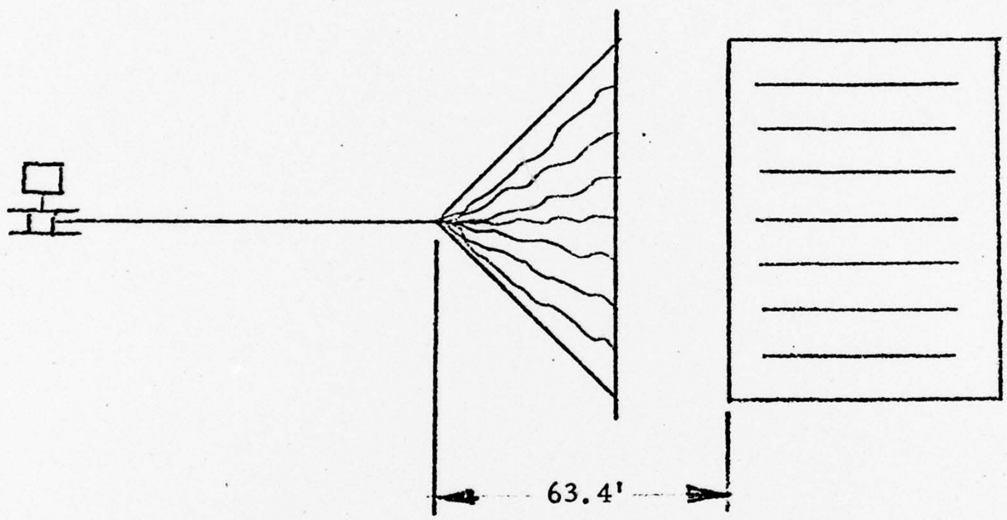
The length of the mat must be at least the range of strokes $\left(S_{max} - S_{min}\right)$ plus one vehicle length plus an allowance for the uncertainty in engagement position and line stretch. Until a rope material is finally selected and tested we will very conservatively estimate all uncertainties and stretch to be less than 10 ft.

$$\text{Length of Mat (min)} = \left(S_{max} - S_{min}\right) + \ell_{veh.} + 10 \text{ ft.}$$
$$= 27.8 \text{ ft.}$$

A.2.3 Position of Mat

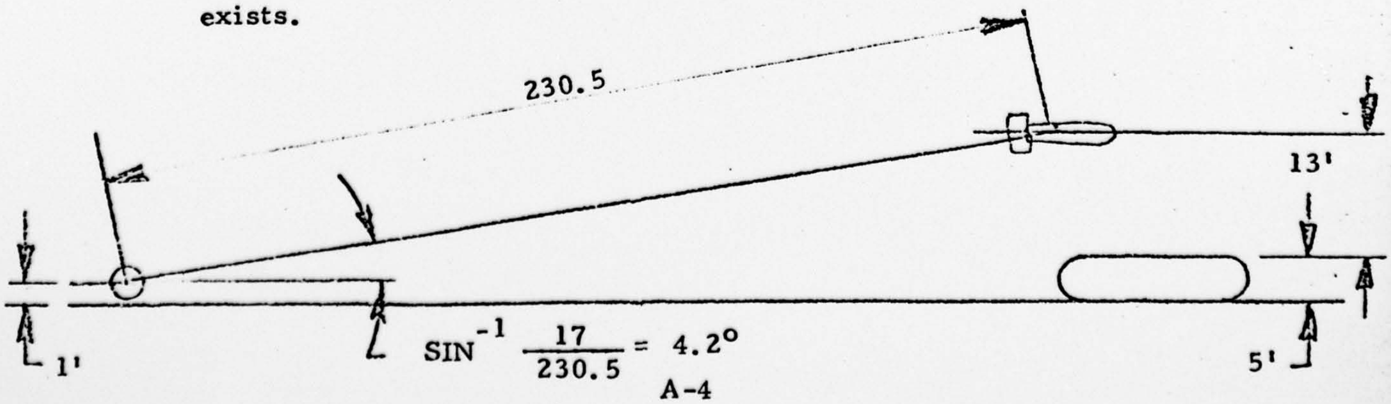
Since engagement will be to the aft of the vehicle, and a short stroke recovery also corresponds to the case of minimum stretch, the leading edge of the mat will be positioned a distance from the fan-out ring equal to the length of the individual arrestor lines plus the minimum stroke.

$$\left(X_{ring} - X_{\substack{L.E.\\mat}}\right) = 55.5 + 7.9 = 63.4 \text{ ft.}$$

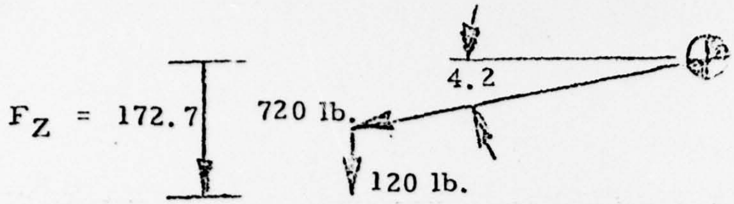


A.2.4 Maximum Vertical Impact Velocity

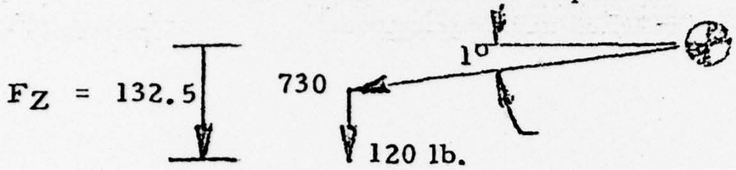
The maximum vertical impact velocity occurs with maximum deceleration force and a hit high in the window, say 18 ft. When the lines are fully stretched, prior to deceleration the following situation exists.



The initial force vector on the vehicle's c.g. is:



The force vector on impact is:



Thus, the average vertical force is:

$$\overline{F_Z} = 153 \text{ lbs.}$$

impact velocity is:

$$V = \sqrt{2as} = \left(2\,\frac{153}{120}\,3213\right)^{1/2} = 32.6 \text{ f/s}$$

A.2.5 Required Mat Thickness

If the vertical deceleration is a constant 6 g's after impact, the minimum vertical travel will be:

$$S = \frac{1}{2}\,\frac{V^2}{a} = \frac{1}{2}\,\frac{(32.6)^2}{6 \times 32} = 2.8 \text{ ft.}$$

Since there will actually be some initial force build-up, we will use a conservative 5 ft thickness.

A.2.6 Required Mat Pressure

Maximum mat pressure should be 7 times the vehicle weight distributed over the wing area.

$$P = \frac{7 \times 120}{35} = 24 \text{ psf} = 4.6 \text{ in. } H_2O$$

A.2.7 Mat Outflow

Mat outflow must accommodate the initial vertical velocity to avoid pressure overshoot.

$$Q = V_Z S_{wing} = 32.6 \times 35 = 1,141 \text{ ft}^3/\text{sec}$$

A.2.8 Orifice Size

The orifice size must allow the maximum outflow at the maximum pressure since the orifice will be fully opened only under these conditions.

$$P = 1/2 \rho V^2$$

$$\text{where,} \quad V = \frac{Q}{A}$$

$$P = 1/2 \rho \frac{Q^2}{A^2}$$

$$A = \left(\frac{\rho}{2} \frac{Q^2}{P}\right)^{1/2}$$

$$A = \left(\frac{.00738}{2} \frac{(1141)^2}{24}\right)^{1/2} = 8.0 \text{ ft.}^2$$

If there are 4 orifices the diameter of each will be:

$$D = \sqrt{\frac{4}{\pi} \cdot 2} = 1.6 \text{ ft.} = 19.2 \text{ in.}$$

Note that we have over-sized the orifices - spring loaded poppets will be adjusted for the proper P - Q relationship and a stop provided to limit the total area to the calculated value.